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Final Technical Report

"Chondritic Meteorites: Nebular and Parent-Body Formation Processes"

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There are no patents or inventions associated with this grant.

Summary of Research:

It is important to identify features in chondrites that formed as a result of parent-body modification in order to disentangle nebular and asteroidal processes. However, this task is difficult because unmetamorphosed chondritic meteorites are mixtures of diverse components including various types of chondrules, chondrule fragments, refractory and mafic inclusions, metal-sulfide grains and fine-grained matrix material. Shocked chondrites can contain melt pockets, silicate-darkened material, metal veins, silicate melt veins, and impact-melt-rock clasts. This grant paid for several studies that went far in helping to distinguish primitive nebular features from those produced during asteroidal modification processes.

We found that many petrologic and geochemical properties of CO3 chondrites (i.e., abundance of amoeboid olivine inclusions (AOI), percentage of rimmed AOI, bulk O-isotopic composition, type of refractory inclusion and mean chondrule size) are not nebular in origin, but can be accounted for by hydrothermal alteration on the CO parent body. An extensive follow-up study of AOIs in CO3 chondrites has revealed many details of the alteration process and has resulted in the development of a more accurate classification system for CO chondrite metamorphism/alteration.

We marshaled the evidence for the impact-vaporization/fractional-condensation model of formation of large metal nodules in ordinary chondrites. We argued against the recent model of Kong et al. (1998) that the nodules were formed by normal thermal metamorphic processes.

In the first major study of the Portales Valley meteorite breccia, we suggested that the precursor rock was a normal H chondrite that experienced impact melting, separation of metal and troilite from silicate to form coarse metal veins, and reintroduction of troilite into the silicate, possibly via a vapor phase. That this process may be a common one is indicated by the occurrence of a IIE iron meteorite (Netschaëvo) and an EL6 chondrite (Blithfield) with analogous textures. The inferred impact-heating origin for Portales Valley supports the model of impact heating for OC parent bodies.

We studied the Smyer H-chondrite impact-melt breccia and noted that adjacent to silicate-rich melt veins are regions consisting of shattered (but unmelted) silicate grains and chondrule fragments surrounded by troilite. Numerous narrow fractures in the silicates are also filled with troilite. The troilite/metal ratio in some of these regions is ~1000/1, far higher than the eutectic ratio of ~7.5/1. Rubin proposed that the troilite was vaporized during the impact event, dissociated, transported as S_2, and recondensed around the shattered silicates where it scavenged Fe from adjacent metal grains.

We also completed a comprehensive study of the halite-bearing Zag H-chondrite regolith breccia and began elucidating its diverse alteration history. This history includes thermal metamorphism and multiple, overlapping episodes of brecciation and aqueous alteration.

We studied the new Gujba bencubbinite, the only known fall of this meteorite class. Gujba consists of 41 vol.% large round metal nodules, 20 vol.% large light-colored, chondrule-like, silicate nodules, and 39 vol.% dark-colored, silicate-rich matrix. We showed that the metal and silicate nodules appear to have formed by high-temperature condensation processes in an impact plume created during a major impact into the regolith of a chondritic parent asteroid.

We analyzed a centimeter-size nodule of metallic Fe-Ni situated at the interface between silicate melt and a relict chondritic clast in Rose City and found that the metal is highly fractionated: one end is enriched in refractory siderophiles (including Os and Ir, but excluding W) relative to bulk H chondrite metal and the other end is depleted in Os and Ir, but less so in W. We explained this unusual composition by a complicated process involving shock-vaporization of chondritic material, followed by condensation of refractory siderophiles, oxidation of W to form volatile oxides, transport of the residual vapor (containing common and volatile siderophiles as well as W-oxide) through fractures over a distance of a few millimeters and condensation of this vapor onto an available surface.

Bibliographic References to Publications Released During Research Period

1. Rubin A.E., Scott E.R.D. and Keil K. (1997) Shock metamorphism of enstatite chondrites. *Geochim. Cosmochim. Acta* **61**, 847-858.
2. Rubin A.E. (1997) Mineralogy of meteorite groups. *Met. Planet. Sci.* **32**, 231-247.
3. Rubin A.E. (1997) Igneous graphite in chondritic meteorites. *Mineral. Mag.* **61**, 699-703.
4. Rubin A.E. (1997) The Galim LL/EH polymict breccia: Evidence for impact-induced exchange between reduced and oxidized meteoritic material. *Met. Planet. Sci.* **32**, 489-492.
5. Rubin A.E. (1997) Sinoite (Si_2N_2O): Crystallization from EL chondrite impact melts. *Amer. Mineral.* **82**, 1001-1006.
6. Rubin A.E. (1997) Mineralogy of meteorite groups – An update. *Met. Planet. Sci.* **32**, 733-734
7. Rubin A.E. (1998) Correlated petrologic and geochemical characteristics of CO3 chondrites. *Met. Planet. Sci.* **33**, 385-391.
8. Rubin A.E. (1999) Formation of large metal nodules in ordinary chondrites. *J. Geophys. Res. – Planets* **104**, 30,799-30,804.
9. Rubin A.E., Verish R.S., Moore C.B. and Oriti R.A. (2000) Numerous unpaired meteorites exposed on a deflating playa lake at Lucerne Valley, California. *Meteorit. Planet. Sci.* **35**, A181-A183.
10. Rubin A.E., Ulff-Moller F., Wasson J.T. and Carlson W.D. (2001) The Portales Valley meteorite breccia: Evidence for impact-induced metamorphism of an ordinary chondrite. *Geochim. Cosmochim. Acta* **65**, 323-342.
11. Rubin A.E., Zolensky M.E. and Bodnar R.J. (2002) The halite-bearing Zag and Monahans (1998) meteorite breccias: Shock metamorphism, thermal metamorphism and aqueous alteration on the H-chondrite parent body. *Meteorit. Planet. Sci.* **37**, 125-141.
12. Rubin A.E. (2002) The Smyer H-chondrite impact-melt breccia and evidence for sulfur vaporization. *Geochim. Cosmochim. Acta* **66**, 683-695.

Other papers stemming from this research are in press, but were not published during the grant period.